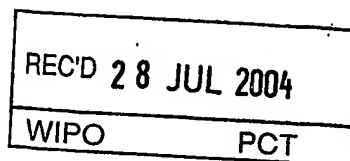# KONGERIKET NORGE
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Anvendelse av polarisasjon for å skille ulike typer
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Oppfinnelsens område

Den foreliggende oppfinnelse vedrører bruk av polarisasjon
for å skille QoS klasser, samt å skille nyttelast og hode
i pakker innenfor kommunikasjonsnettverk. Mer generelt
5 omhandler oppfinnelsen en ny og forbedret utnyttelse av
polarisasjonstilstander i sin alminnelighet innenfor alle
typer kommunikasjonsnettverk.

Oppfinnelsens bakgrunn

Med innføringen og utviklingen av optiske nett er det et
10 mål å redusere kostnadene for overføring av data i Tele og
datanettverk. Et viktig moment for kostnadsreduksjon er i
økende grad å redusere antall signalkonverteringer mellom
optisk og elektronisk form. En slik reduksjon vil gi et
redusert antall komponenter i nettverkselementene og
15 redusere behovet for elektronisk signalprosessering. Disse
momentene gir igjen potensiale for en kostnadsreduksjon.

Ved erstatning av elektroniske nettverkselementer med
optiske nettverkselementer er det derfor nødvendig at de
optiske nettverkselementene har en funksjonalitet som kan
20 fungere effektivt i et pakkesvitsjet nettverk. I denne
forbindelse er det de seneste årene gjort mye forskning på
optisk pakkesvitsjing, og optisk burstsvitsjing der
pakker, eller burst's av pakker svitsjes direkte i det
optiske laget med optiske svitsjer. De nevnte teknikker
25 antas å begynne å bli kommersielt interessante om omtrent
fire år.

De fem dimensjoner

Siden optisk signalprosessering fremdeles er i sin
barndom, er det svært begrensede muligheter for å
30 signalere ulike typer informasjon som for eksempel
adresseinformasjon. Dimensjoner som er tilgjengelig for
overføring av informasjon i en optisk fiber er:

Intensitet, tid, frekvens, fase og polarisasjon. Alle
disse dimensjonene er opp gjennom årene foreslått benyttet
til ulike formål.

Modulasjonsformatene som benyttes i optiske linker og
5   nettverk i dag er basert på NRZ og RZ formatet der
Intensitet varieres mellom et minimum og maksimumsnivå.
Signalene er tidsmultiplekset med en datarate på mellom
2,5 og 40 Gb/s. I optiske linjesvitsjede nettverk benyttes
den optiske frekvensen til å multiplekse flere
10 tidsmultipleksede kanaler på en fiber (WDM). Den optiske
frekvensen er også foreslått brukt som merkelapp i optiske
nettverk der rammeverket fra MPLS benyttes. Fase er
foreslått benyttet som modulasjonsform for å øke spektral
effektivitet, gjerne i kombinasjon med polarisasjon.

15 <u>Optisk pakkesvitsjing, adresse, QoS og signalering</u>

I forbindelse med optisk pakkesvitsjing er overføring av
adresseinformasjon i form av en header eller label, en
problemstilling. Normalt i en elektronisk ruter sendes
headeren i starten på pakken eller rammen, og
20 adresseinformasjon og nyttelast er dermed
tidsmultiplekset. Med bruk av optiske komponenter er det
vanskelig å demultiplekse i tidsplanet. Overføring av
adresseinformasjon separat fra nyttelasten er derfor
foreslått utført på ulike måter. Adresse og nyttelast
25 skilles ved å bruke separate optiske bølgelengder, gir
dårlig utnyttelse av bølgelengdene. Bruk av en separat
frekvens innenfor den optiske bølgelengden, såkalt Sub
Carrier Modulation (SCM), som utnytter den optiske
båndbredden bedre en når en separat bølgelengde benyttes,
30 men som kan gi forringelse av nyttelastsignalet. I IST
prosjektet "STOLAS" foreslås det å benytte fasemodulasjon
for modulasjon av pakkeheader separat fra nyttelasten,
også denne metoden kan gi forringelse av signalkvaliteten
i nyttelasten.

Kjente prinsipper

1)   Bruk av polarisasjon for multipleksing/demultipleksing av to datakanaler (polarisasjonsmultipleksing) på en fiber er et kjent
5   prinsipp. Det er derfor kjent at man generelt kan skille informasjon med denne metoden.

2)   Bruk av polarisasjon til å finne start og stopp på en bit-sekvens er kjent, altså signalering ved å skifte polarisasjonstilstand

10   3)   Å skille ulike optiske datakanaler med polarisasjon på samme måte som ulike optiske datakanaler kan skilles på bølgelengde. Optiske add/drop enheter basert på å skille mellom ortogonale polarisasjoner er i likhet med liknende enheter som skiller ved bruk av bølgelengde

15   **QoS differentiation and header/payload separation in optical packet switching using polarisation multiplexing**

Introduction

Optical packet switching (OPS) is promoted as a way to overcome the electronic bandwidth bottleneck. However, if
20   OPS nodes are to be realised, they must also prove to be cost effective. In this paper we propose using polarisation multiplexing for a low-cost separation and reinsertion of control information in OPS, as well as for optical differentiation between Quality of Service (QoS)
25   classes. The two applications can be performed simultaneously or separately.

Several techniques have been proposed for in-band header encoding, like serial header, Sub-Carrier Modulation (SCM), and Frequency Shift Keying (FSK). However, they
30   require advanced components for separatation of header and payload, and reinsertion of new headers. To erase old

header, before a new one can be inserted, per input
wavelength, serial header requires a fast optical gate
e.g. a Semiconductor Optical Amplifier (SOA), while SCM
and FSK need an optical wavelength converter. This
5   increases component count of complex and yet
technologically immature components. Furthermore, if
separation of packets belonging to different QoS classes
is desirable, it will normally be done based on electronic
processing of the header information, hence not all-
10   optical.

The technique proposed here overcomes these drawbacks by
using orthogonal States Of Polarisation (SOP) for
separating packets and sending control information. By
using a Polarisation Beam Splitter (PBS) per wavelength
15   for header/payload separation, the complexity and cost may
be reduced significantly, compared to the solutions
mentioned above.

**A highly efficient optical packet switching node design
supporting guaranteed service**

20   <u>Introduction</u>

The traffic volume of Internet is reported to show a
significant increase despite the downturn of the
telecommunication industry. Hence, increasing parts of the
traffic in the transport network origins from packet data.
25   For obvious economic reasons, new switching techniques
should first be introduced at the time they show maturity
and cost effectiveness. Hence there is a need to develop
flexible optical networks supporting a seamless migration
from an optical circuit switched (OCS) to an optical
30   packet switched (OPS) backbone network.

In a statistical multiplexed packet switched network,
services like constant delay, and no packet loss, can not
be guaranteed due to the very nature of statistical

multiplexing. This may preclude the use of strict real-time applications, where delay is critical, and packet loss should be at an absolute minimum, like e.g. for remotely controlled surgery. Guaranteed service (GS),

5 without contention causing packet loss, and a fixed delay, can however be offered if the packets are sent through a network following a path with pre-assigned resources, like in a Static or Dynamic Wavelength Routed Optical Network (S-WRON or D-WRON). D-WRONs increases throughput

10 efficiency, compared to S-WRONs, by dynamically reconfiguring the wavelength paths to adapt to the traffic demands. However, the control plane operates on a ms to s timescale, and cannot be optimized to the bursty traffic patterns of OPS, where packet durations are typically in

15 the µs range. Therefore, not even D-WRONs can achieve the throughput efficiency and granularity of statistical multiplexing. In this paper we propose combining the properties of a statistically multiplexed packet switched network (OPS) with the GS enabled by optical circuit

20 switched networks (like S-WRON/D-WRON) in a single optical network layer. This requires that the circuit switched GS packets and the OPS packets efficiently share the data layer resources. We propose a node design that allows full sharing of link bandwidth, and that allows a migration

25 from a S-WRON to the more efficient combined network, by adding OPS capability. The efficiency of the node is studied using a simulator.

Muligheter for pakkesvitsjen

Pakkesvitsjen kan være dels optisk og dels elektronisk,
30 eller heloptisk som beskrevet i de to avsnittene i dette kapittelet.

Det er i EP 07944684 A1 beskrevet et optisk pakkesvitsjet nettverk med en eller flere noder og en transmitter som sender polariserte pakkesignaler. Pakkesignalene
35 inneholder en header og nyttelast som er skilt fra

hverandre ved hjelp av ortogonal polarisering. Vider er
det kjent fra CA 2352113 en optisk kommunikasjonsmetode
der det anvendes høyhastighets polarisert bit innfelling.
Metoden går ut på å bruke polarisert bit innfelling for å
5   skille datapakker fra hverandre i stedet for å multiplekse
datastrømmer fra forskjellige modulatorer. Dette øker
hastigheten for overføring av data i et optisk nettverk.

Kort beskrivelse av oppfinnelsen

Den foreliggende oppfinnelse søker å avhjelpe de foran
10   omtalte problemer knyttet til dagens kjente løsninger,
idet

Kort beskrivelse av tegningene

De vedlagte tegninger som er inkludert i og utgjør en del
av spesifikasjonen illustrerer utførelser av den
15   foreliggende oppfinnelsen og, sammen med beskrivelsen
tjener den til å forklare prinsippene med oppfinnelsen.

Figur 1 viser pakker tilhørende to ulike QoS klasser
tilordnes relativt ortogonale polarisasjonstilstander. Det
blir dermed mulig i mottakeren å skille de to
20   prioritetsklassene optisk ved bruk av en enkel
polarisasjons strålesplitter.

Figur 2 viser the proposed node design. The resources used
in the l-switch and packet switch are shared. The number
of inputs needed equals the number of input fibres X the
25   number of link-wavelengths, GS = Guaranteed Service. & =
Optical And Gate.

Figur 3 viser experimental setup. PC = Polarisation
Controller

Figur 4 viser Figure 4, Sensitivity curves for the two signals, both for back-to-back (stippled lines) and at the egress node. Modulating both transmitters simultaneously.

Figur 5 viser Figure 5, The OPS part of the node is shown
5 as an embedded part of an S-WRON node with a hardwired cross coupling matrix. In the S-WRON configuration example, each of the nodes connected to the inputs have 'k' wavelength-connections available to each of the outputs. The fixed wavelength converters enable on-line
10 reconfiguration of the S-WRON. FDL = Fibre Delay Line, n= number of link-wavelength. N = Number of link inputs

Figur 6 viser Figure 6 (top, 32 1) and 7 (below, 128 1), X/Y-axis: Number of buffer interfaces/PLR. Error bars marks 95% confidence interval. No GS = pure BE system.

15 Figur 7 viser

Figur 8 viser Figur 8, skisse av hybridsvitsjen. Ruteren kan håndtere to QoS klasser, Beste effort og en første prioritets trafikk. Lysets polarisasjon brukes til å signalere QoS klassen. Best effort håndteres elektronisk,
20 første prioritets trafikk optisk. I den optiske svitsjen er det bølgelengden som bestemmer hvor pakken forwardes.

Figur 9 viser Fig.9, A scalable design with QoS priority. Whether the packet will have priority or not, is decided by the state of polarisation of the packet at the input.

25 Figur 10 viser Figure 10, A network with a number of nodes and QoS connections between some of these.

Figur 11 viser Figure 11, The COST 266 reference scenario. It has a total of 37 nodes, and a maximum node degree of 5.

30

Detaljert beskrivelse av oppfinnelsen

Bruk av polarisasjonssignalering

En kan tenke seg at signaleringen kan brukes på flere
alternative måter:

5 a)   Synkronisering, polarisasjonstilstanden endres ved
start av hver pakke.

b)   Header og payload i pakke skilles med orthogonale
polarisasjonstilstander

c)   QoS klasser skilles ved å tilordne pakker som skal
10 behandles med ulik prioritet, ulik polarisasjon på
sendersiden.

I figur 1 er det gitt et eksempel på hvordan
polarisasjonstilstand kan benyttes til optisk å skille
mellom to forskjellige QoS klasser. Samme prinsipp kan
15 benyttes til å skilne optisk mellom en header og en
payload. Metoden kan, med bruk av en polarisasjons-
strålesplitter; skille informasjon uavhengig av
bølgelengde. Sendes et WDM signal med mange bølgelengder
inn på splitteren, vil splitteren fungere som en
20 demultiplekser av header og payload (QoS klasser) for alle
bølgelengdene.

Polarisasjon er tidligere foreslått brukt til
synkronisering i optiske tidsdelt multiplekede systemer
(OTDM). I et system der N rammer tidsmultiplekses sammen,
25 tilordnes den første rammen i hver sekvens av N rammer en
polarisasjonstilstand som er orthogonal til de andre
rammenes tilstand. I mottakeren benyttes denne
informasjonen til å ekstrahere en rammeklokke som benyttes
ved demultipleksing.

Applications

Figure 2 illustrates the proposed principle. Header and
payload separation is implemented by sending the header in
an SOP labelled '1', and the payload in SOP '2',
orthogonal to '1'. Separation is done using a PBS,
allowing full transparency with respect to bitrate and
signal format for both header and payload.

Additionally, if a very high QoS is needed with a
Guaranteed Service (GS) with respect to packet loss and
delay, like e.g. remote image guided surgery, the GS
packets may be forwarded solely on the basis of their
wavelength information using a wavelength router. These
packets can be separated from e.g. Best Effort (BE)
packets by transmitting BE packets in SOP '2', while GS
packets are transmitted in the SOP '1', like in figure 2.
GS packets will then pass through a wavelength routed
network allowing GS, while BE packets will be interleaved
with the GS packets at the output of each node, increasing
the utilisation of the links.

Both the described applications can be combined. GS
packets will then be sent in SOP '1', without an
orthogonal polarisation header, while BE packets will be
sent in the SOP '2' with a simultaneously transmitted
header in SOP '1'. When a signal is observed in SOP '1',
with a signal simultaneously present in SOP '2', the
signal in SOP '1' is recognised as the header of a BE
packet. If there is no signal simultaneously present in
SOP '2', the signal is recognised as a GS packet. When
using this method, detection of the simultaneous presence
of signals in the two SOP's enables distinction of GS
packets and BE headers. If serial BE header is used,
distinction can be implemented sending the signals from
the two SOP's into an optical AND gate. The GS packets in
SOP '1' are forwarded through the AND gate if SOP '2' is

high, while if SOP '2' is low, a BE header in SOP '1' is present, and blocked by the gate.

If only one application is implemented, BE and GS packets, or a header and a BE packet, can be sent simultaneously in both SOPs. This has the potential of doubling the link's bandwidth utilisation.

Experiment

The transmission properties of the principle have much in common with polarisation multiplexing: Depending on the fibre's birefringence, PMD and the link distance, signals are depolarised. However, unlike conventional polarisation multiplexing, where a polarisation demultiplexing is done only at the receiver node, our technique includes polarisation demultiplexing, polarisation, SOP re-alignment and polarisation multiplexing in all intermediate "core nodes". This increases tolerance to depolarisation and changes in SOPs, thereby allowing longer transmission distances.

In our experiment, we demonstrate the quality of the signal path through a network model performing one of the described applications. The experimental set-up, corresponding to a network consisting of an ingress node, a core node and an egress node, is shown in figure 3. Two optical transmitters on the same wavelength are modulated at 2.488 Gb/s using two separate and decorrelated bit generators with PRBS of length $2^{11}-1$. The signals are combined using a polarisation maintaining (PM) coupler, and amplified using an EDFA. After the first 25 km SMF link, the signals arrive at the "Core Node". A manual Polarisation Controller (PC) ensures an ideal SOP to allow optimum splitting of the two signals in a PBS. To emulate forwarding of the signals, the two arms are combined using a PM coupler, and sent to the receiver node, through the second 25 km SMF link. Here, the two signals are again

realigned and separated, before sent to the receiver. Power penalties are found comparing transmission path and back-to-back Bit Error Rate (BER) curves in different configurations. Because of the polarisation variations

5   occurring in the fibre due to variations in the fibres environmental conditions, like temperature variations, SOPs at the PBS inputs must be continuously monitored and optimised. The frequency of the variations caused by the environment is normally lower than an Hz; automatic

10 polarisation optimisation can therefore be used.

Two different transmission schemes, illustrating the two proposed applications, were tested. The transmission characteristics of the header-payload separation is measured using modulation on both transmitters, while

15 segregation of packets belonging to different QoS classes is done by modulating only one transmitter at a time, leaving the other in CW mode. We experienced that the most critical application is when modulating both polarisation states. However, as shown in figure 4, segregating packets

20 was demonstrated with a very moderate penalty. The experimental points are interconnected by a linear fit, taking all but the very last measurement of the two egress node series into account. These are omitted because, during the measurement, drift in absolute SOP's, thus sub-

25 optimum header-payload separation, occured. This can be avoided using automatic PC (not available for the experiment). As shown in figure 4, a maximum penalty of less than 0.5 dB can be observed at a BER of 10^{-9}.

Conclusion

30 We have proposed and investigated the use of polarisation multiplexing for header and payload separation and for optical QoS differentiation in optical packet switched networks. The principle of a packet switch node is described and the quality of the signal path through a

35 network model is experimentally verified. Using this

principle, the need for complex costly components is
significantly reduced, and optical QoS packet segregation
is achieved. A maximum penalty of only 0.5 dB was observed
at the receiver node after passing the suggested optical
packet switch node and 2 X 25 km of SMF.

Node design

The proposed node design is shown in figure 5. An OPS
module, using the same principles as known from S.
Bjornstad et.al. "A scalable optical packet switch for
variable length packets employing shared electronic
buffering". ECOC 2002,vol.3,2002. P 4.7

is added to a S-WRON node. Packets are divided into two
classes: "GS", that follows the pre-assigned S-WRON path,
and a Best Effort class, "BE", without service guarantees,
that is switched using the packet switch module. At the
input, the two packet classes are segregated by setting
1x2 switches based on information in a header, or as shown
in the figure 5 by using orthogonal States Of Polarization
(SOP). Then each of the polarization states is assigned to
each of the service classes.

Since the GS packets destinations are decided by the
configuration of the cross coupling matrix and the
individual wavelengths of the packets, like in figure 5,
GS headers are superfluous. Since service class
segregation is achieved using SOP, contrary to other
proposed principles of optical QoS separation using
reservation of wavelengths in an OCS network, the
wavelength domain can be entirely devoted to wavelength
routing purposes.

If a GS packet arrives at the switch, the control
electronics register that a packet is present at the input
before the packet is delayed in a FDL corresponding to the
duration of a maximum sized BE packet, D_{BEMAX}. The output

for which the packet is scheduled is then reserved. If a
BE packet is currently propagating through the reserved
output, it will not collide with the newly arrived GS
packet, because of the delay in the FDL. Alternativly, the
5   output can be reserved D_{BEMAX} in advance of the GS packet
arrival by sending a control packet. If SOP is used for
segregating the packet classes, the control packet should
be sent in the same SOP as the GS packet, enabling
simultaneous transmission with potentially earlier
10 transmitted BE packets.

Performance analysis

Packet delay and packet loss is found by simulation.
Independent, asynchronous traffic generators, generating
fixed length packets are used. The BE packets have a
15 length of 500 B, while the GS packets length is varied,
and set to either 500 B or 50 kB. An output is reserved
D_{BEMAX} before a GS packet that arrives at the input enters
the output.

The packets interarrival times are negative exponential
20 distributed (Poisson), corresponding to a load of 0.8 of a
maximum load on each wavelength. Packet arrivals, both BE
and GS, are uniformly distributed at the switch inputs. BE
packet destinations are uniformly distributed, thereby
also among the outputs. The GS packets are forwarded to a
25 fixed destination and wavelength, uniformly distributed,
hence avoiding congestion with other GS packets.

Electronic buffering is assumed, therefore the BE packets
can stay in the buffer for an arbitrary period of time.
There is no limit on the size of the buffer, however the
30 registered maximum filling of the buffer was 632 packets.
The use of a very large buffer is therefore avoided.
Buffered packets are normally scheduled as soon as a
destined output becomes available, but reordering of
packets may occur in rare cases.

The node performance is analysed in a transport network for 32 and 128 wavelengths at a node-degree of 8, varying the number of buffer inputs. The maximum delay measured, was 0.21 times the packet duration, in the case of 60

5   buffer inputs, 50 % GS traffic share, 50 kB GS packet length, also giving maximum buffer filling. This is normally much lower than the transmission delay and hence negligible. The simulation results showing PLR, for GS packet share of 10% and 50 % of the total traffic load,

10   measured in bytes, are shown in figure 6 and 7, respectively.

In both figures we compare the performance with a system with only BE traffic. When the PLR for the pure BE traffic is 10^{-6}, for 32 wavelengths and a GS packet length of 500

15   bytes, the degradation is two decades for a 10 % GS traffic share, while for 50 % GS traffic share the degradation is more than three decades. If a GS packet length of 50 kB is used, the 50% and 10% curves are overlapping, and the degradation is one decade. Figure 7,

20   for 128 wavelengths, show the same tendency. At a pure BE system PLR of 10^{-6}, degradation can be observed for GS packets when the packet length is 500 Bytes. At a GS traffic share of 10%, the degradation is approximately one decade, and for 50 % GS traffic, the degradation is

25   approximately three decades. Worth noticing is that when the number of buffer interfaces is further increased, causing lower PLR's, degradation is observed also when using GS packets of 50 kB length. At a pure BE system PLR of 10^{-7}, the degradation is one half of a decade and one

30   decade for 10% and 50% GS traffic shares, respectively.

Figures 7 and 8 illustrates that the overhead caused by the reservation time is the main reason for the PLR degradation. Generally, a degradation increasing with the decreasing PLR and thus, number of interfaces, can be

35   observed. When the GS packet length is large (50 kB), the degradation is low, independently of the GS traffic share.

However, when GS and BE packets have equal length, the degradation may be several decades. From the simulation results we conclude that the PLR penalty is low if the GS packets are much longer than D_{BEMAX}. Since GS packets are

5   given absolute priority, the very low BE PLR penalty observed, even when 50 % of the total traffic is GS packets, may come as a surprise. However, when increasing the number of GS packets in the system, the number of BE packets are decreased, causing less problems with

10 contention between BE packets and less load on the available buffer resources.

Conclusions

An OPS node design supporting GS without packet loss and with fixed delay, as well as a BE service class is

15 proposed. The design supports a migration strategy from circuit to packet switching by starting with an S-WRON module and adding an OPS module. High capacity utilisation is obtained by interleaving statistically multiplexed BE packets with GS packets that follow a pre-assigned

20 wavelength path. The penalty of introducing GS packets in the system is shown to be very moderate if the GS packets is much longer than the BE packets. Aggregation of GS packets into bursts must therefore be considered.

Hybrid elektronisk/optisk svitsj med QoS

25 Dette avsnittet beskriver en hybrid konstruksjon der en svitsj bygges opp med en optisk forwarding av en kvalitetsklasse (GS) og en elektronisk forwarding av en annen kvalitetsklasse (BE). Figur 8 viser en skisse av svitsjens oppbygging.

30 Svitsjen har to svitsjematriser, en elektronisk og en optisk svitsjematrise. Den elektroniske svitsjematrisen er mye tenkt å være lik dagens elektroniske svitsjer

svitsjematrise, og fungere sammen med kontrollenheten som
dagens Best Effort svitsjer.

Den optiske svitsjematrisen er tenkt å fungere som en
"bølgelengderuter". En bølgelengde inn sendes til en
5   bestemt fiber og bølgelengde ut. Bølgelengden ut og
fiberen ut settes ut fra bølgelengden og fiberen inn. I
illustrasjonen i figur 8 brukes kun en fiber. Denne
tilnærmingen har likheter med MPLS der bølgelengden kan
betraktes som en label.

10   På inngangen splittes signalet avhengig av det optiske
signalets polarisasjon. Fordelen med dette er at en rent
optisk enhet kan brukes til å splitte trafikk som skal ha
første prioritets håndtering og håndteres som "best
effort". Løsningen forutsetter at avsenderne sorterer
15   prioritert trafikk og Best Effort trafikk ved å sende
disse med relativt til hverandre ortogonal polarisasjon.
Løsningen kan i prinsippet være et tilbygg til en
elektronisk svitsj, der den elektroniske svitsjen beholdes
slik den er i dag, og håndterer best effort trafikk, mens
20   den optiske bølgelengderuteren tar seg av førsteprioritets
trafikk. Konstruksjonen blir da noe annerledes og noe
mindre optimal en vist i figur 8. Det blir ingen mulighet
for den elektroniske svitsjen å la den optiske svitsjen ta
seg av trafikk når sistnevnte har ledig kapasitet.
25   Utnyttelsen av den optiske delen blir derfor noe mindre
optimal, men konstruksjonen blir betydelig forenklet.

I figur 8 er det tenkt at et antall bølgelengder
reserveres til den elektroniske svitsjen og et antall til
den optiske svitsjen. Hvis den optiske svitsjen er et
30   tilbygg, kan dette bølgelengdeantallet være et fast
antall, eller styrt sentralt. Hvis de to svitsjne er
bygget sammen fra starten av, kan antallet bølgelengder
enklere varieres og være dynamisk og håndteres internt i
svitsjen.

Optisk svitsjing av både GS og BE pakker, med mulighet for elektronisk buffring (som foreslått i artiklene /7/ og /8/)

Optical packet switching combined with a GMPLS approach
5   for high QoS packets

Another design example is given in figure 9. By always delaying packets with high priority (QoS packet), outputs can be reserved so that the destined output is vacant when the packet occurs at the output of the optical buffer.

10   In this design BE packets may choose freely among all the wavelengths at the output of the switch. In the first stage of the switch the output wavelengths is chosen. The QoS packets bypasses this first stage, hence the QoS packets input wavelength will decide the output wavelength
15   at the output fibre. To which output fibre the packet is forwarded, is decided by the wavelength set by the packet switch's second row of wavelength-converters. In the third row of wavelength-converters, the wavelength will be set to a fixed wavelength matching the input wavelength of
20   specific input of a mux. Hence there is not possible changing the wavelength.

Contention resolution

Because there is not possible buffering the QoS packets for contention resolution in this design, a reservation
25   scheme will be necessary. Before a QoS packet is transmitted, a wavelength from the transmitter to the destination should be reserved. This implies that each of the receivers will simultaneously be able to receive QoS packets from a number of destinations limited to the
30   number of input wavelengths at the receiver end. To avoid contention, no more than one source will be allowed to generate packets to each of the input wavelengths in a node. Figure 10 illustrates this principle.

In the network shown in figure 10, when QoS information is sent from one node to another, say from node 4, to node 6, a path consisting of one or more wavelengths needs to be reserved all the way through the network, from node 4 to

5   node 6. The reservation implies that no other nodes can transmit QoS information at the reserved wavelength if the wavelengths are sharing the same path (fibre) along the way. If two nodes where transmitting at the same wavelength, contention would occur. Since no buffering is

10 available for QoS packets, packets would have to be dropped.

Wavelengths can both be reused, and added/dropped. As shown in the figure 10, at node N1, the incoming wavelength from node N2, named N2- 4, is dropped at N1,

15 and reused for sending QoS packets from node N1 to node N6 (N1- 4).

Scalability

Normally the node degree in a transportnetwork like this will be in the order of say 4-8. Also the total number of

20 nodes in the transport network will be limited. In COST 266 a reference scenario for a pan European network is given. Figure 11 illustrates this network. In the network a total of 37 Nodes is present, and it has a maximum node degree of 5. The question is whether a static.

25 configuration of QoS resources will be sufficiently effective in a transportnetwork. Whether this is true will depend on the amount of QoS traffic in the network, and the number of wavelengths in each node. The packet switch design described will be effective only when a high number

30 of wavelengths is available. This is because the design relies on using the wavelength dimension for contention resolution. Number of wavelengths should therefore be 32 or more. When 37 nodes are present, a maximum of ...???????? unique wavelengths will be necessary in order to have a

35 full mesh QoS network available.

Dynamic wavelength allocation for scalability

If a dynamic wavelength allocation scheme is employed,
wavelengths can dynamically be set up and taken down on
demand. This will increase the utilization of the
5   resources available for transmitting QoS packets, since it
will allow dynamic changes in the traffic load. If the
node in figure 9. is slightly modified, replacing the
fixed wavelength converters at the output with tunable
wavelength converters, the wavelength for a QoS path can
10 be allowed to change along the way. This will allow a
higher reuse factor of the wavelengths in the network.
However, a technical problem when multiplexing the
unpredictable wavelengths at the output of the tunable
wavelength converters, has to be solved. Normally a low
15 loss multiplexer will be wavelength sensitive. Other
approaches to switching the wavelength in the node may be
evaluated.

Transparent Dynamic line switching and/or Burst switching

The QoS packets do actually not need to be packets. They
20 can be bursts of packets, i.e. burst switching can be
performed, or it can be a semi-permanent line, i.e. line
switching. It will all depend on the preferred approach.
When a QoS packet arrives at the input of the switch, a
change in the state of polarisation will be detected.
25 Hence it is known that it is a QoS packet. At the end of a
QoS packet, the state of polarisation has to be changed
back to the "best effort state" so that when the QoS
packet has passed the polarisation monitor, the switch
will know the end of the packet. The output and the
30 resources in the switch will then be freed, so that
resources can be used by the Best Effort packets.

Since the start and stop of the QoS packets is detected
only by change in state of polarisation, and QoS packets
will never be passed to the buffer, there is no need to

know the content of the information in the QoS packets.
The physical format of the QoS packet, like bitrate and
modulation, can therefore in principle be varied. The
limitations on the transparency will be set by the
5   characteristics of the wavelength converters.

For forwarding of the QoS packets, the destination of the
packet must be known in advance. This is for the switch to
be able to set the wavelength converter in the second row
of converters. The information about the QoS packet should
10 be sent in advance. There are two approaches to this:

Burst switching approach: This principle should be used
if there are few QoS paths in the network, and they will
have to be reused often. QoS paths can be established for
a very short period of time, corresponding to the length
15 of a packet, or a burst of packets.

The information about the destination for QoS packets
occurring at a specific input and wavelength is sent as a
control packet. The control packet can be sent on a
separate wavelength, or at the same wavelength, and will
20 contain a header, telling the destination of the QoS
packet(s). It does not need to contain information about
the length of the packet or burst of packets, since the
state of polarisation will tell the start and stop of the
packets or burst. In burst switching, information about
25 the arrival time of the packet is sent out in advance.
This is for the immediate nodes to be able to reserve
bandwith during a, in the control packet, specified period
of time. However since the QoS packets are always buffered
in the switch in a optical fibre delay line, bandwith
30 reservation is not necessary in advance, it will be done
when the QoS packet arrives at the switch. In addition, a
protocol for distribution of the forwarding information
will be needed. A table containing a mapping between the
address information in the control packet and how to set
35 the wavelength converters is necessary.

Line switching approach: This principle should be used when QoS paths will have a duration that is much longer than a burst of packets. The output wavelength of the wavelength converter will be set to a wavelength according to a table. The table will be updated by a protocol distributing the forwarding information. This implies that no address lookup will be needed when a QoS packet arrives, avoiding processing. However, there will be a mapping between a specified input (wavelength), and a specified output wavelength, that can be changed only by updating the table. The speed of the dynamic allocation of QoS paths will therefore be limited by the protocol updating the table.

Utilization of the QoS paths

The node design in figure 9. allows the QoS paths to be utilized by BE packets when QoS packets are not present. The lights state of polarisation is used for differencing between QoS and BE packets. Therefore, most of the capacity not used by the QoS traffic can be used by the BE packets by interleaving these packets in between the QoS packets or bursts. Technically, it is possible to transmit both QoS and BE packets simultaneously when the polarization is orthogonal. This implies doubling the capacity in the fibre, however this also implies a number of technical challenges with respect to the transmission quality of the signal, since interference between the signals in the two states of polarisation will occur.

Therefore, in this approach, BE and QoS packets are sent in a serial manner, avoiding degradation of signal quality due to interference.

When the node design in figure 9 is used, BE packets can be buffered and allocated a random wavelength along the path to its destination. This allows the capacity of the wavelengths, and also the wavelengths or paths reserved

for transmission of QoS packets, to be efficiently
utilized. When no QoS packet is present at a reserved QoS
path, a BE packet can, if it is available at one of the
inputs or in the buffer, be switched to the reserved QoS
5   path.

When a QoS packet occurs at the input of the switch
(node), the packet will be sent in to an optical buffer
with a delay corresponding to the length of the longest BE
packet. While the QoS packet is in the buffer, the
10   reserved QoS path at the output of the switch will be left
vacant from the time when the last packet at this output
has left the output until the QoS packet reaches the
output of the buffer. The optical buffer will give a
predictable delay, thus causing no jitter, with a
15   magnitude insignificant compared to the transmission delay
in the fibre between the nodes.

Referanser

Mike J. O' Mahony et.al. "The application of Optical Packet Switching in Future Communication Networks", IEEE communication Magazine, March 2001, pages 128-135.

5   Chunming Qiao et.al. "Labeled Optical Burst Switching for IP-over-WDM Integration" IEEE Communication Magazine, September 2000. Pages 104-114.

N. Ghani et al. "On IP over WDM integration", IEEE communication magazine, March 2000, pp. 72-83.

10   Betti, S.; Curti, F.; De Marchis, G.; Iannone, E Fondazione Ugo Bordoni, Rome, Italy, "A novel multilevel coherent optical system: 4-quadrature signalling" Journal of Lightwave Technology, page(s): 514 - 523 April 1991, Volume: 9 Issue: 4

15   Blumenthal, D.J.; Carena, A.; Rau, L.; Curri, V.; Humphries, S. Dept. of Electr. & Comput. Eng., California Univ., Santa Barbara, CA, USA, "WDM optical IP tag switching with packet-rate wavelength conversion and subcarrier 20   multiplexed addressing", Optical Fiber Communication Conference, 1999, and the International Conference on Integrated Optics and Optical Fiber Communication. OFC/IOOC '99. Technical Digest, page(s): 162 - 164 vol.3. 21-26 Feb. 1999

25   Xu Lei; Yao Minyu; Cheng Minghua; Zhang Jianfeng; Cheng Xingzhong; Gao Yizhi; Chih-Hsiao Chen, "All optical frame clock extraction with polarization flag in OTDM system", Communications, 1999. APCC/OECC '99. Fifth Asia-Pacific Conference on ... and Fourth Optoelectronics and 30   Communications Conference , 1999 Page(s): 361 -363 vol.1

24

1   Guillemot, et.al. "Transparent optical packet switching: the European ACTS KEOPS project, approach." Journ. Lightwave Techn. 16, pp 2117 -2134, 1998.

2   Blumenthal, D.J "Photonic packet and all-optical label switching technologies and techniques"

OFC 2002 , 17-22 March 2002, pages: 282 -2843

3   Sulur, T. K. et.al. "IM/FSK Format for Payload/orthogonal Labeling IP Packets in IP over WDM Networks Supported by GMPLS-based LOBS." ONDM 2003, February 3-5, 2003, Budapest, Hungary.

4   Bjornstad et.al. "A highly efficient optical packet switch node design supporting guaranteed service", submitted to ECOC 2003, Sept 21-25 Rimini, Italy.

5 J. Hansryd et.al. "Impact of PMD on Four-Wave-Mixing-Induced Crosstalk in WDM Systems." IEEE photonics Technology letters, vol.12, No. 9. September 2000, page 1261-1263.

1   M. J. O' Mahony et.al. "The application of optical packet switching in future communication networks", IEEE Comm. Mag., vol. 3, no. 3, pp. 128-135, 2001.

2 S. Bjornstad et.al. "A scalable optical packet switch for variable length packets employing shared electronic buffering". ECOC 2002,vol.3,2002. P 4.7

3 S. Bjornstad et.al. "QoS differentiation and header/payload separation in optical packet switching using polarisation multiplexing" submitted to ECOC 2003, 2003.

4 A. Jukan et.al. "Quality-of-Service Routing in Optical Networks" ECOC 97, 1997, pp. 160-163.

Patentkrav

1. Et system for signalering innenfor optisk
pakkesvitsjede nettverk
k a r a k t e r i s e r t   v e d at det anvendes to eller
5   flere polarisasjonstilstander for signalering.

2. Et system i henhold til krav 1
k a r a k t e r i s e r t   v e d at nevnte
polarisasjonstilstander endres ved start av hver nye
pakke.

10   3. Et system i henhold til krav 1
k a r a k t e r i s e r t   v e d at nevnte
polarisasjonstilstander endres mellom hode og nyttelast
for å skille nevnte hode fra nevnte nyttelast innenfor den
respektive pakke.

15   4. Et system i henhold til krav 1
k a r a k t e r i s e r t   v e d at de forskjellige
polarisasjonstilstander anvendes for å skille QoS klasser.

5. Et system i henhold til krav 4
k a r a k t e r i s e r t   v e d at QoS klassene
20   bestemmes ved at avsender styrer polarisasjonstilstanden

6. Et system i henhold til krav 4
k a r a k t e r i s e r t   v e d at det er den deriverte
av nevnte polarisasjonstilstand som anvendes for å skille
en eller flere QoS klasser.

25   7. Et system i henhold til ett av kravene 1-3
k a r a k t e r i s e r t   v e d at det anvendes en
polarisasjonsstrålesplitter for å skille mellom to eller
flere polarisasjonstilstander.
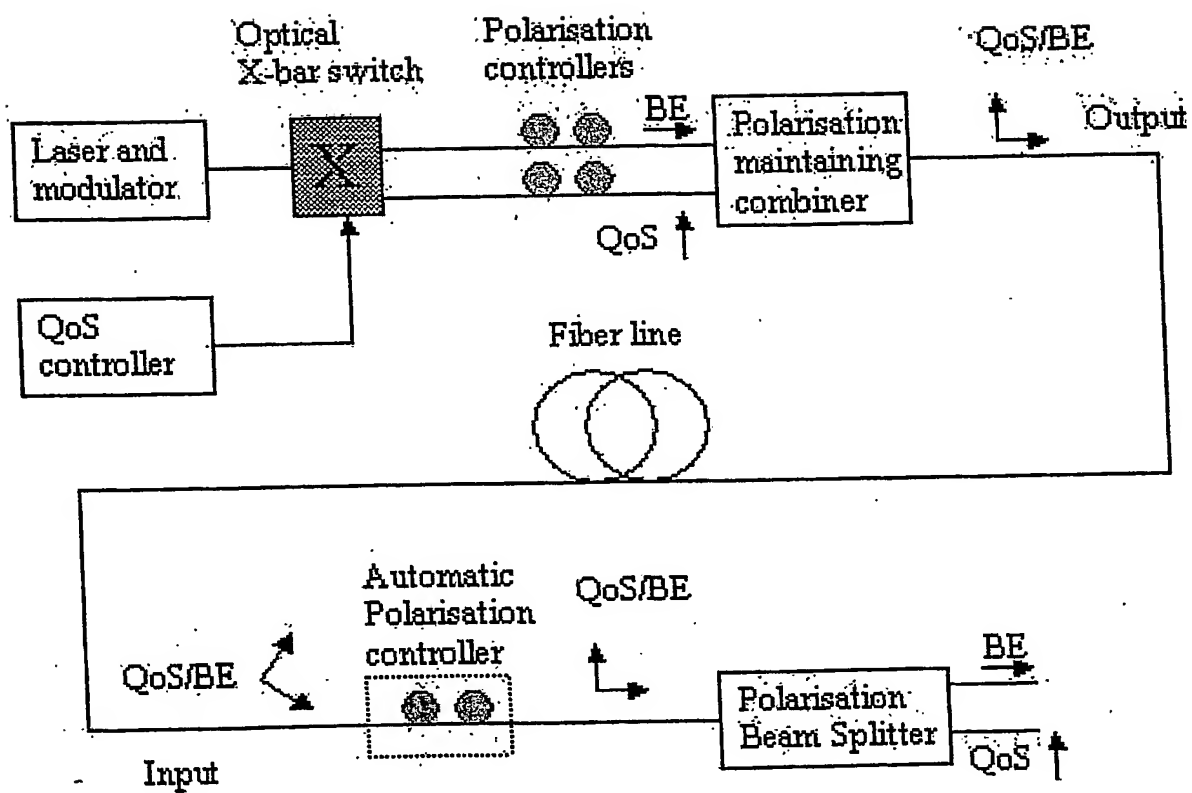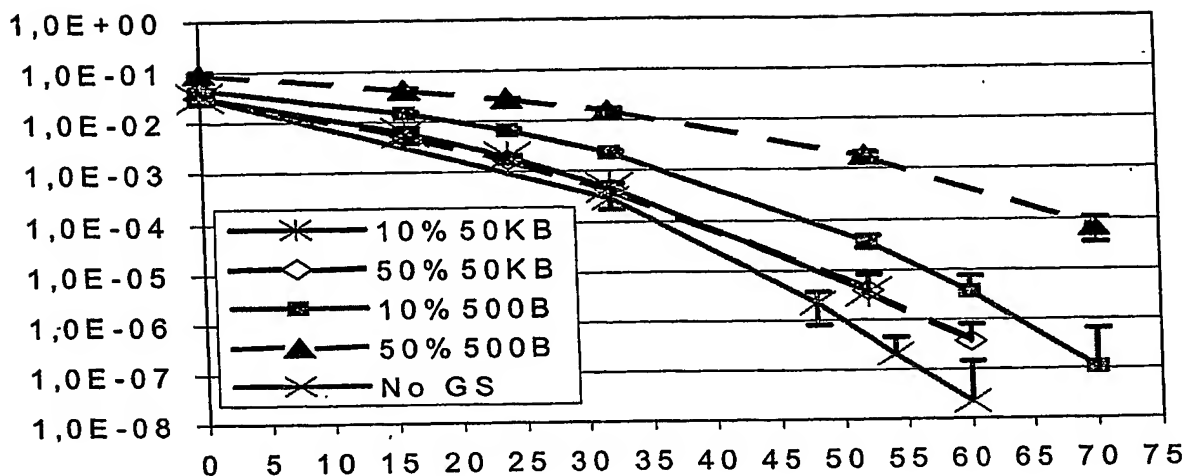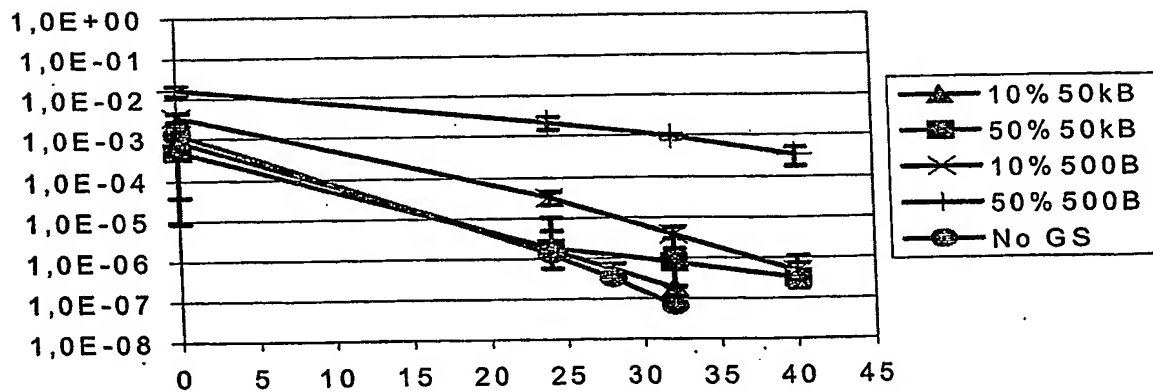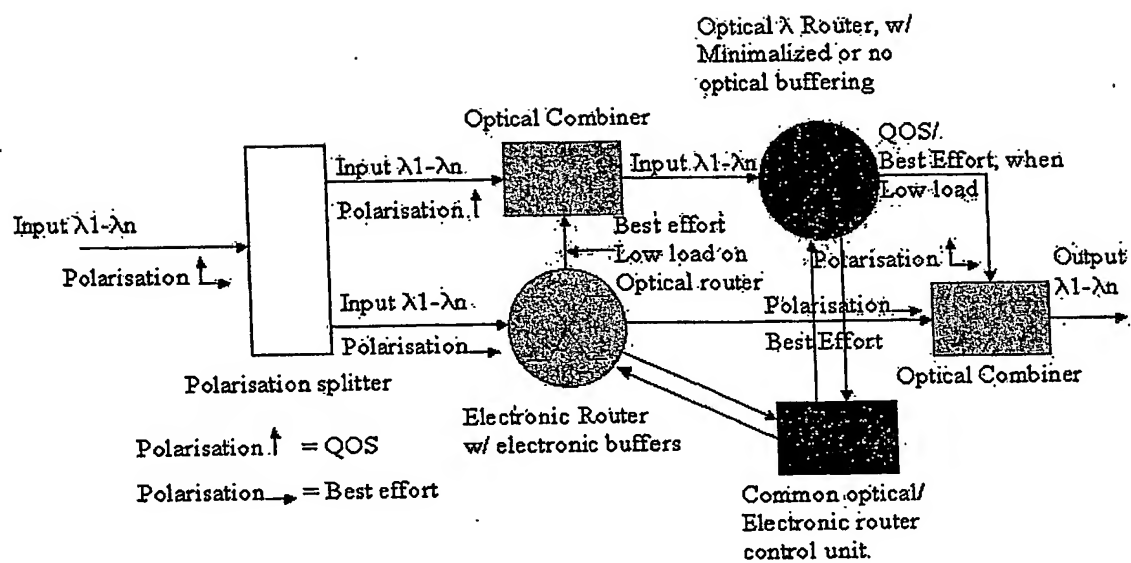
Figure 1

Figure 2

Figure 3

BER vs. Received Power
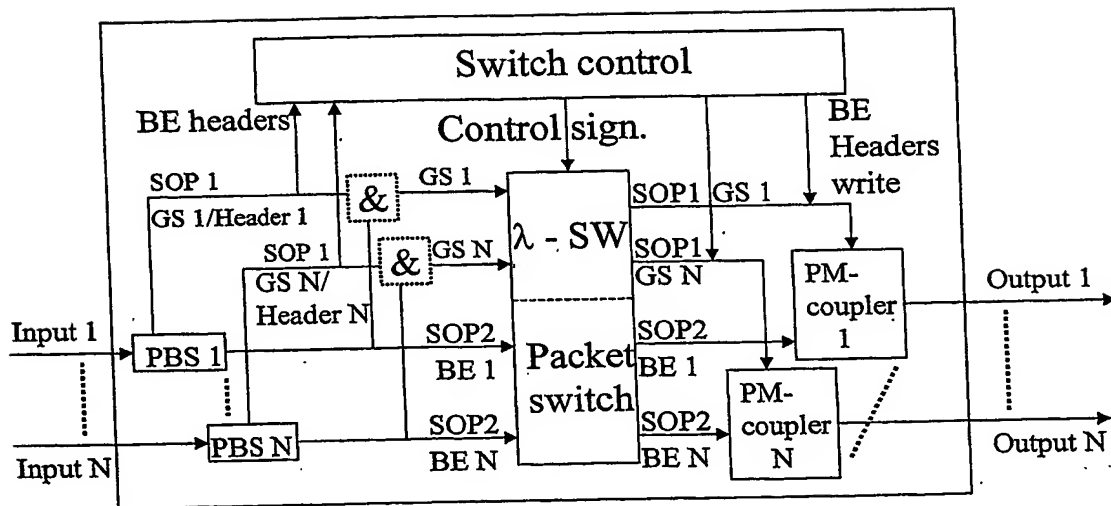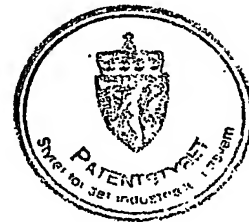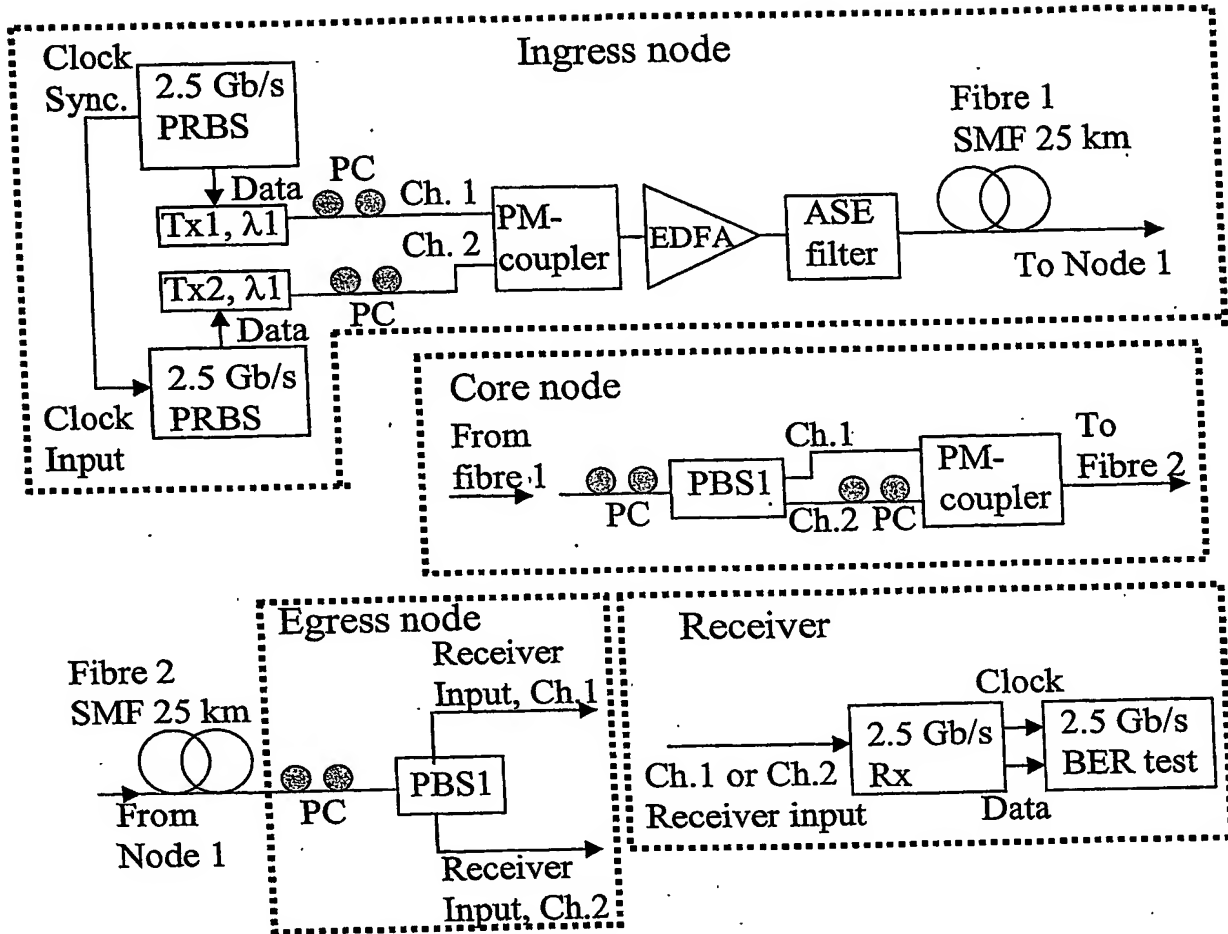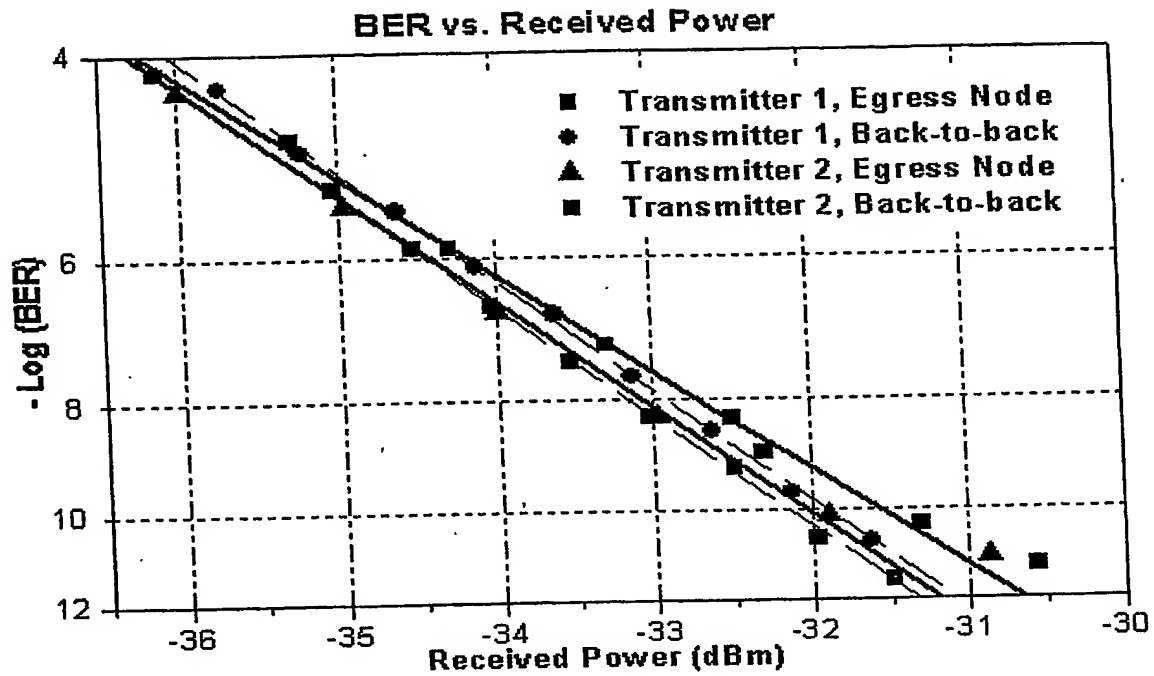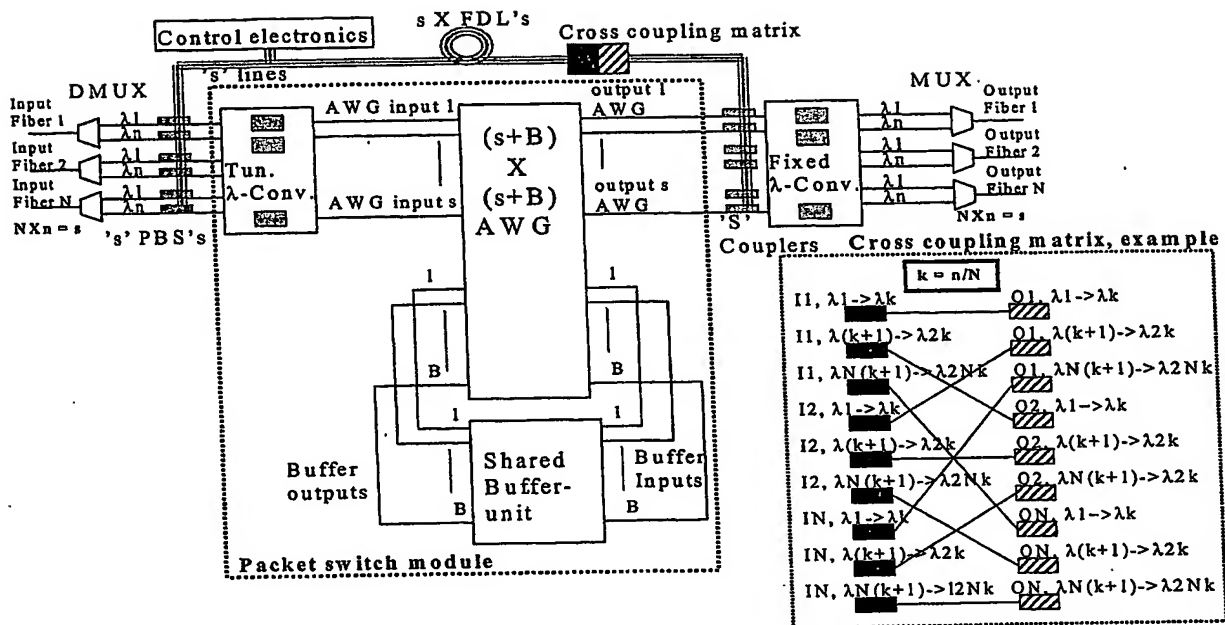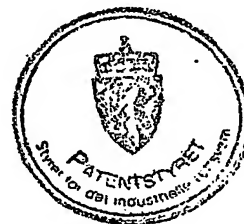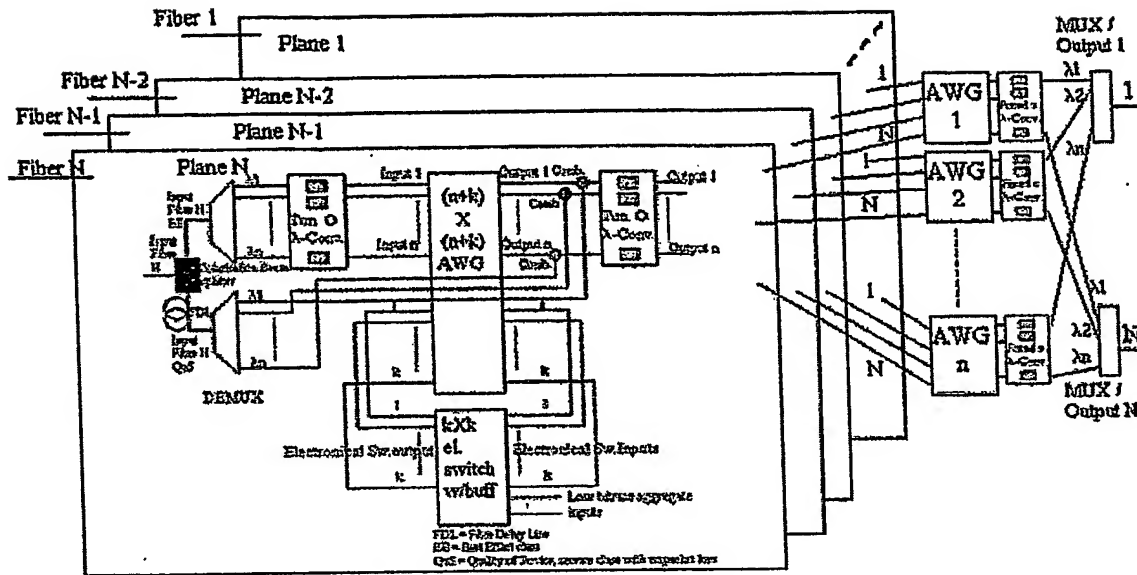
Figure 4

Figure 5

Figure 6

Figure 7

Figur 8

Figure 9

input

N3−λ1, N4-λ2, N5-λ3, N2-λ4

Figure 10

Figure 11